

Solar-to-Grid

Trends in System Impacts, Reliability, and Market Value in the United States with Data Through 2019

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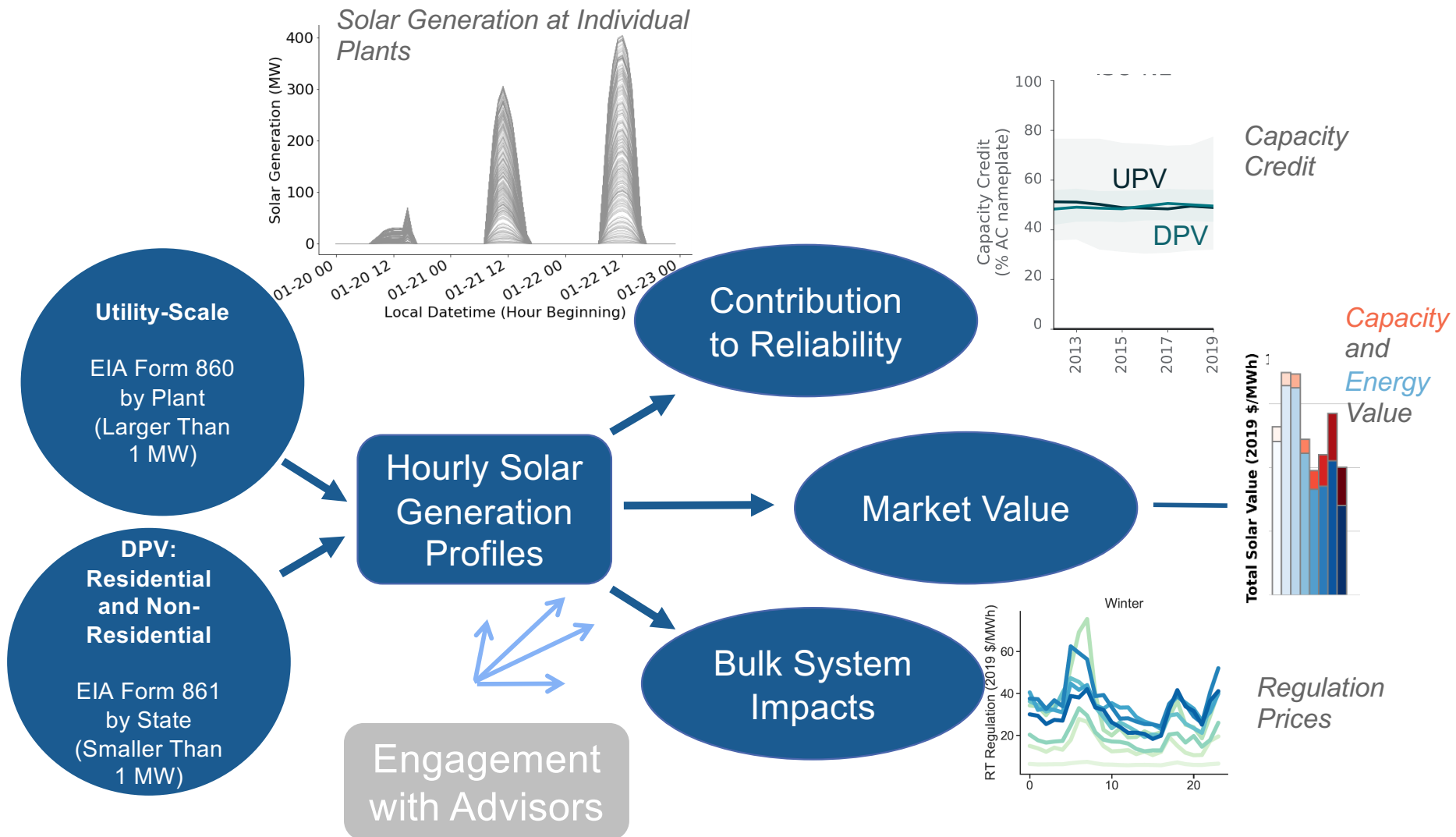
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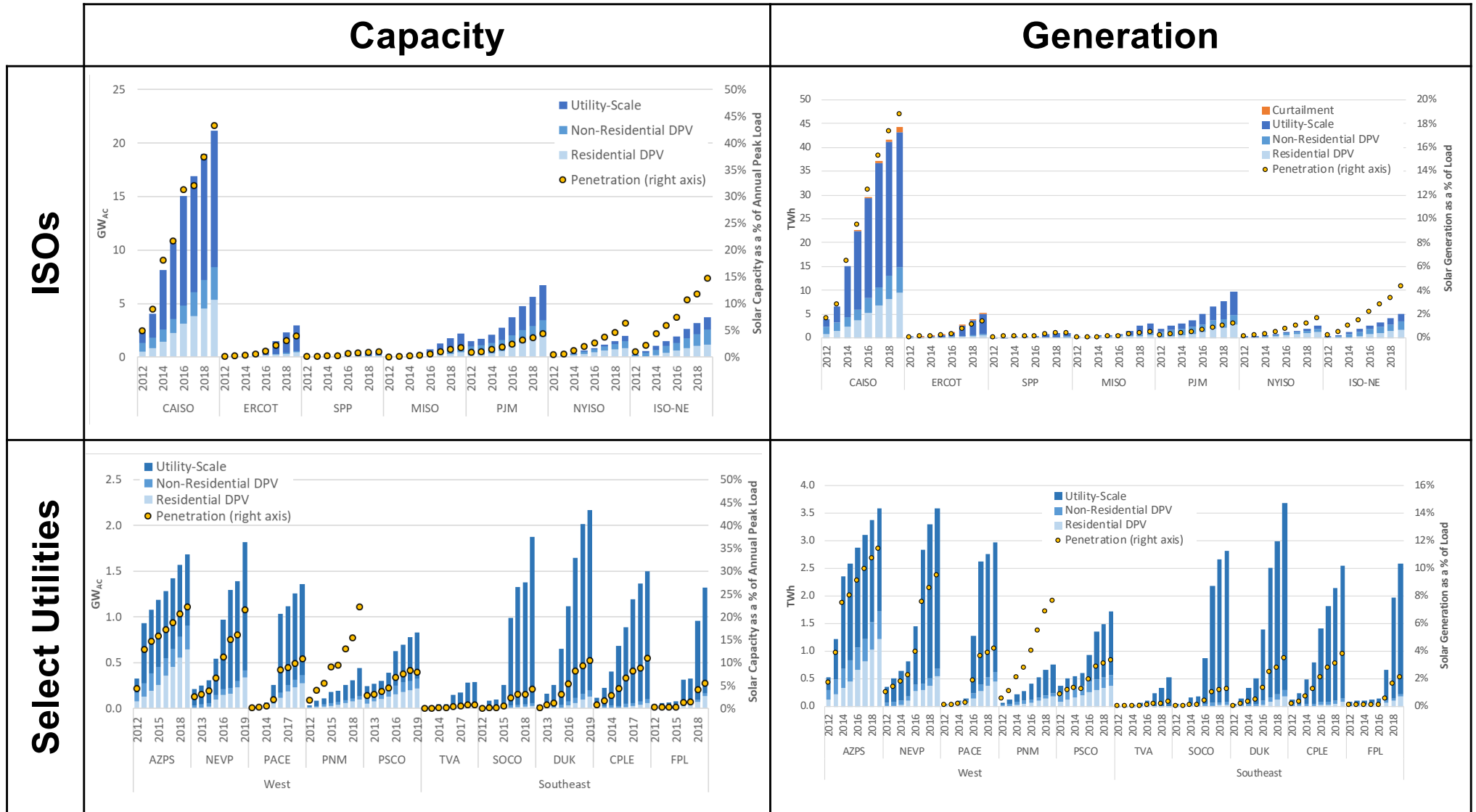
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Goal: improve decision making through information on the observed market value and grid impacts of solar



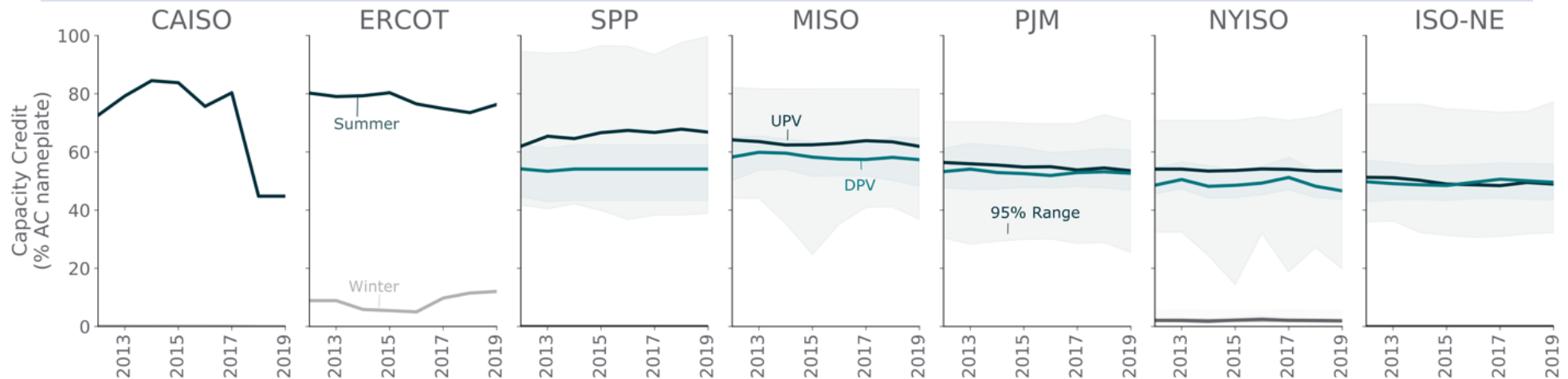
Solar deployment in CAISO far exceeds the level in other ISOs



Capacity credit of solar

Average summer capacity credits in 2019 range from 45–76%, capacity credit is near zero in winter

Capacity credit of solar is calculated by methods used by each market. CAISO shifted to an “effective load carrying capability” method in 2018, PJM filed with FERC to do the same in 2021.



	CAISO	ERCOT	SPP	MISO	PJM	NYISO	ISO-NE
Basis of measurement	ELCC	Average generation in top 20 peak hours	Generation exceedance level during top 3% peak hours	Average generation during peak period	Average generation during peak period	Average generation during peak period	Median generation during peak period
Frequency of measurement	Monthly	Summer, fall, winter, spring	Summer, winter	Summer	Summer	Summer, winter	Summer, winter
Summer peak period	N/A	N/A	June–Sept	June–Aug 2–5 pm	June–Aug 2–6 pm	June–Aug 2–6 pm	June–Sept 1–6 pm
Winter peak period	N/A	N/A	Dec–Mar	N/A	N/A	Dec–Feb 4–8 pm	Oct–May 5–7 pm
Averaged over which years?	N/A	Rolling average over previous 3 years	All available years up to 10 previous years	Rolling average over previous 3 years	Rolling average over previous 3 years	Previous year	Rolling average over previous 5 years
Credit varies for UPV vs. DPV?	No	No	Yes	Yes	Yes	Yes	Yes

Market value of solar

Market value approach and assumptions

Energy Value

$$\text{Energy Value} = \frac{\sum \text{Postcurtailment Generation}_h * \text{Wholesale RT Energy Price}_h}{\sum \text{Percurtailment Generation}_h}$$

- Plant-level debiased hourly solar generation
- Real-time energy price from nearest pricing node
- Focus on annual value of solar from all sectors

Capacity Value

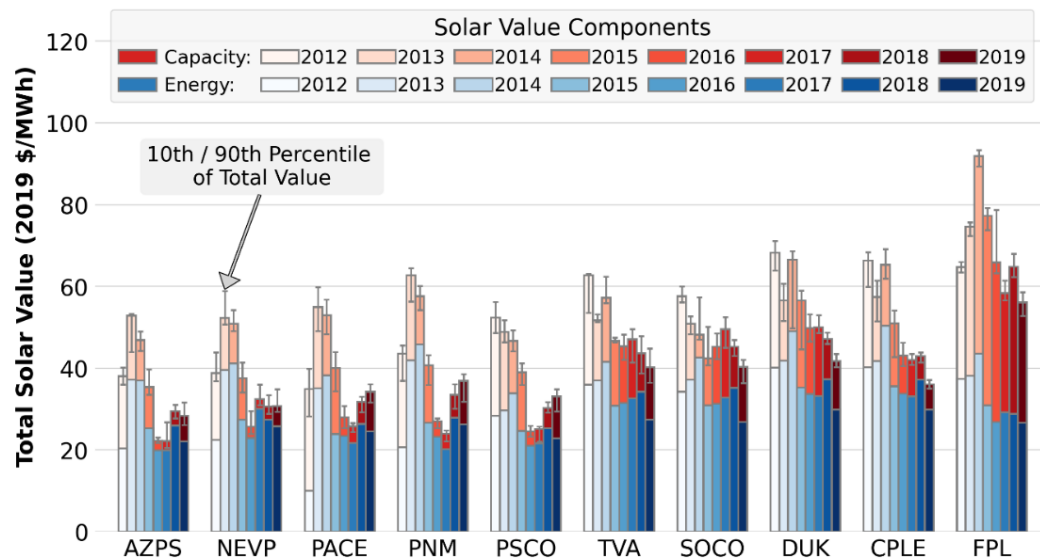
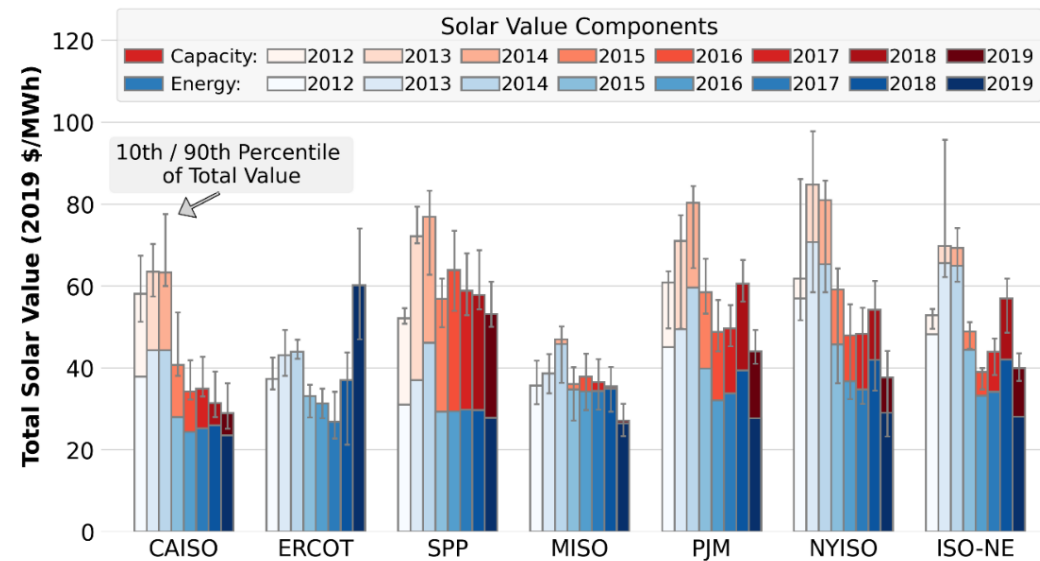
$$\text{Capacity Value} = \frac{\sum \text{Capacity Credit}_T * \text{Nameplate} * \text{Capacity Price}_T}{\sum \text{Percurtailment Generation}_T}$$

- Capacity credit based on plant-level profile; varies by month, season, or year
- Capacity prices from respective ISO region; prices vary by month, season, or year
- Estimate bilateral capacity prices for regions without organized capacity markets
- Focus on annual value of solar from all sectors
- Calculate capacity value for all solar, even if some solar does not participate in capacity markets

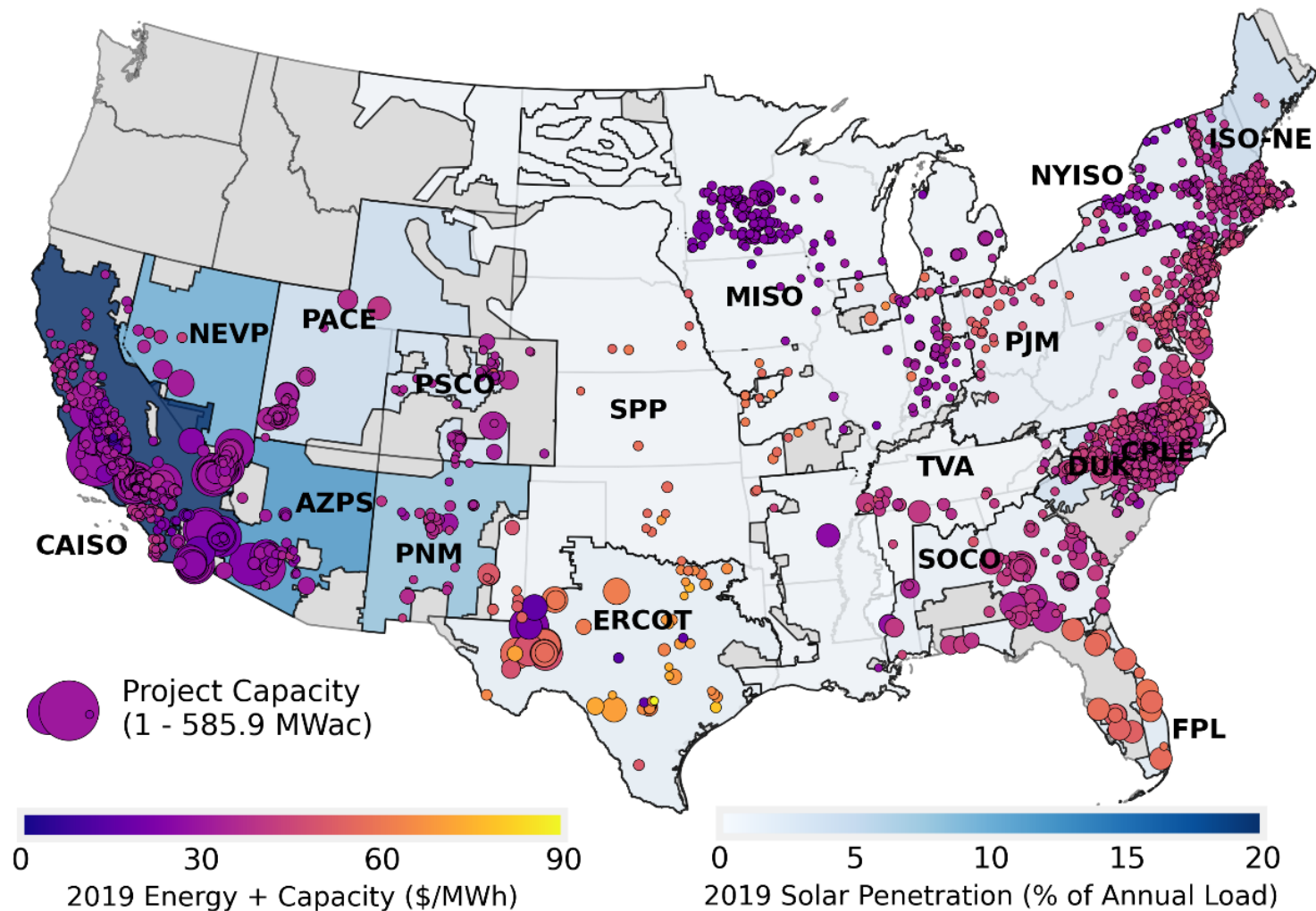
- No AS value, REC value, wholesale price effects, or externalities included in market value
- Energy + capacity value represents the marginal value to the power system



Variations in average energy and capacity prices largely drive differences in the market value of solar



Wholesale market value of solar, by plant in 2019

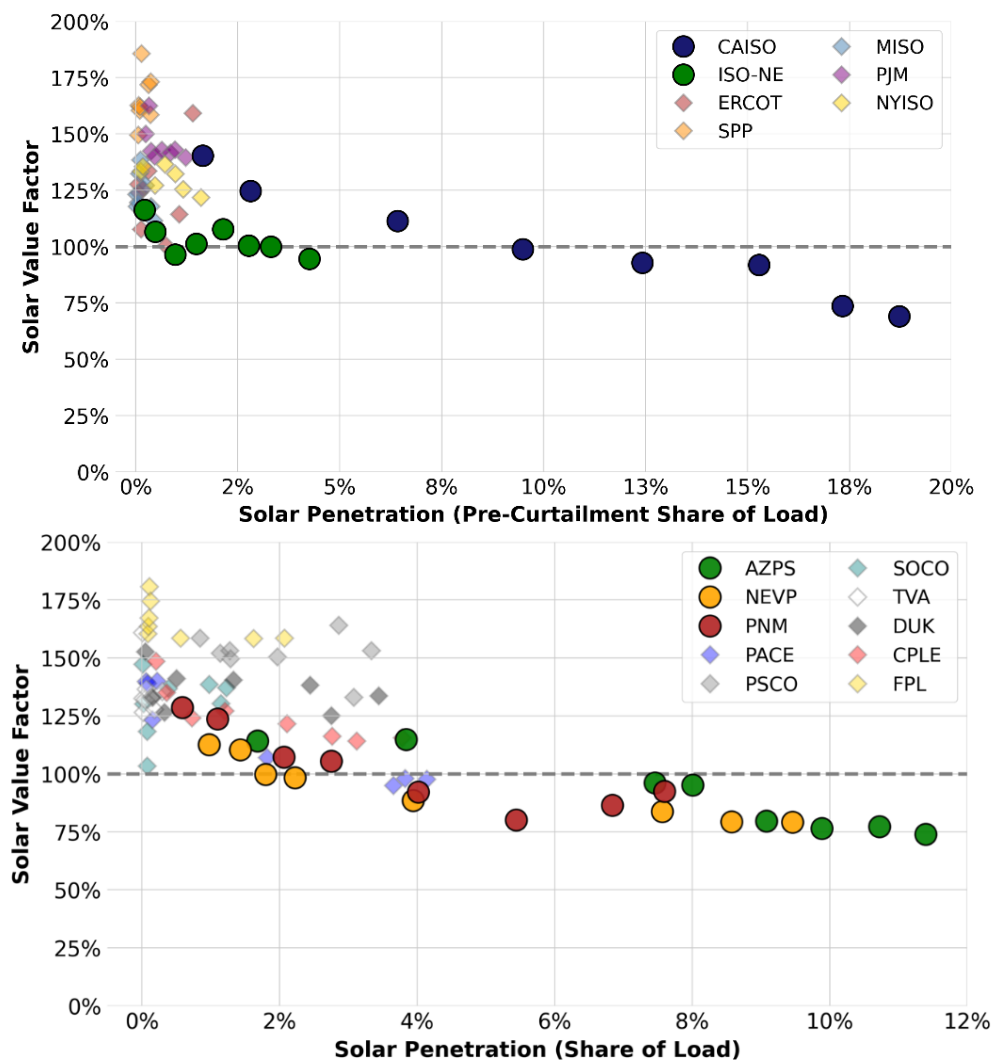


Note: Only plants larger than 1 MW are shown

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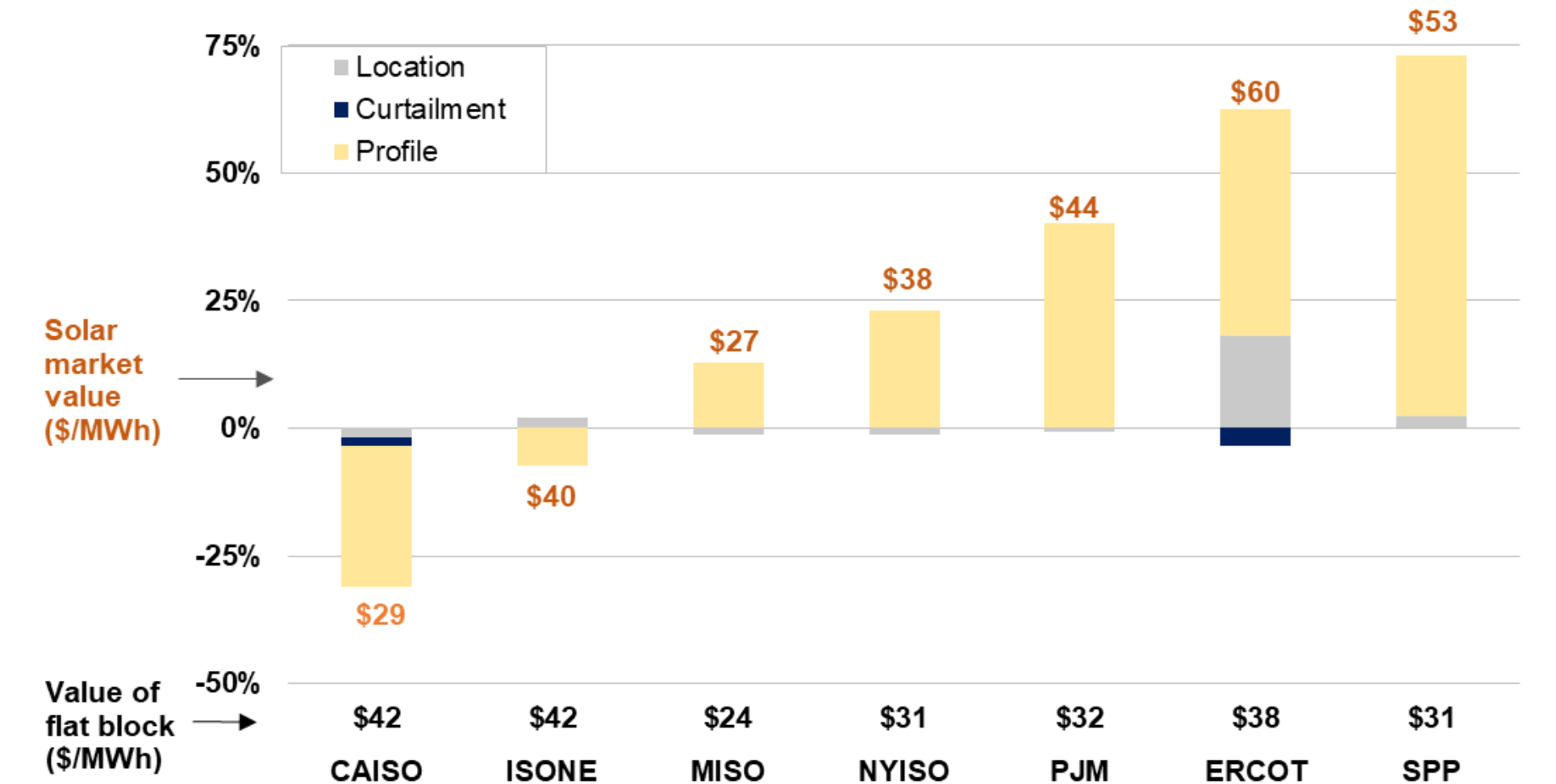
Market value of solar declines with higher solar penetration relative to average prices



Value factor = wholesale market value of solar relative to generalized flat block of power in region; generalized flat block is 24x7 average price across all pricing nodes in region



Market value relative to a flat block is primarily due to the timing of the solar profile, rather than solar location



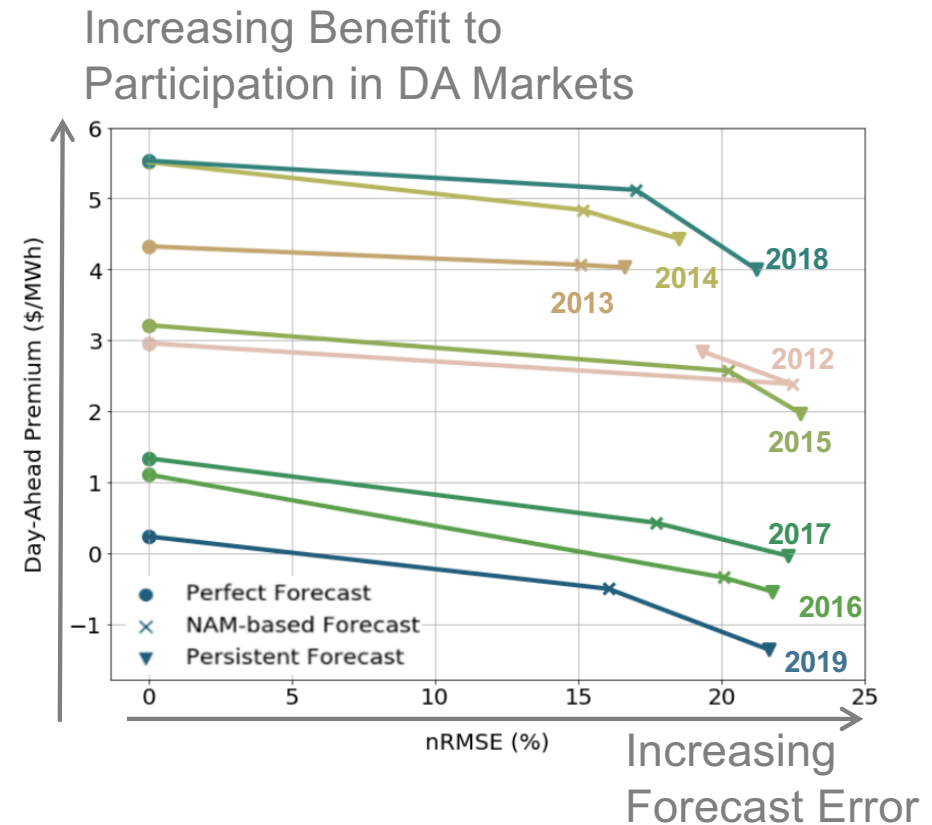
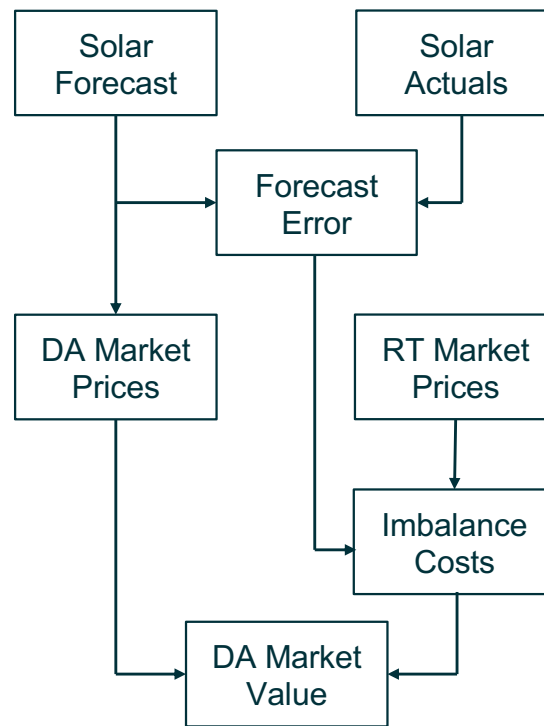
Note: Flat block is 24x7 average price across all pricing nodes in region

Benefit of participating in day-ahead (DA) markets is insensitive to forecasting skill

Only RT Market

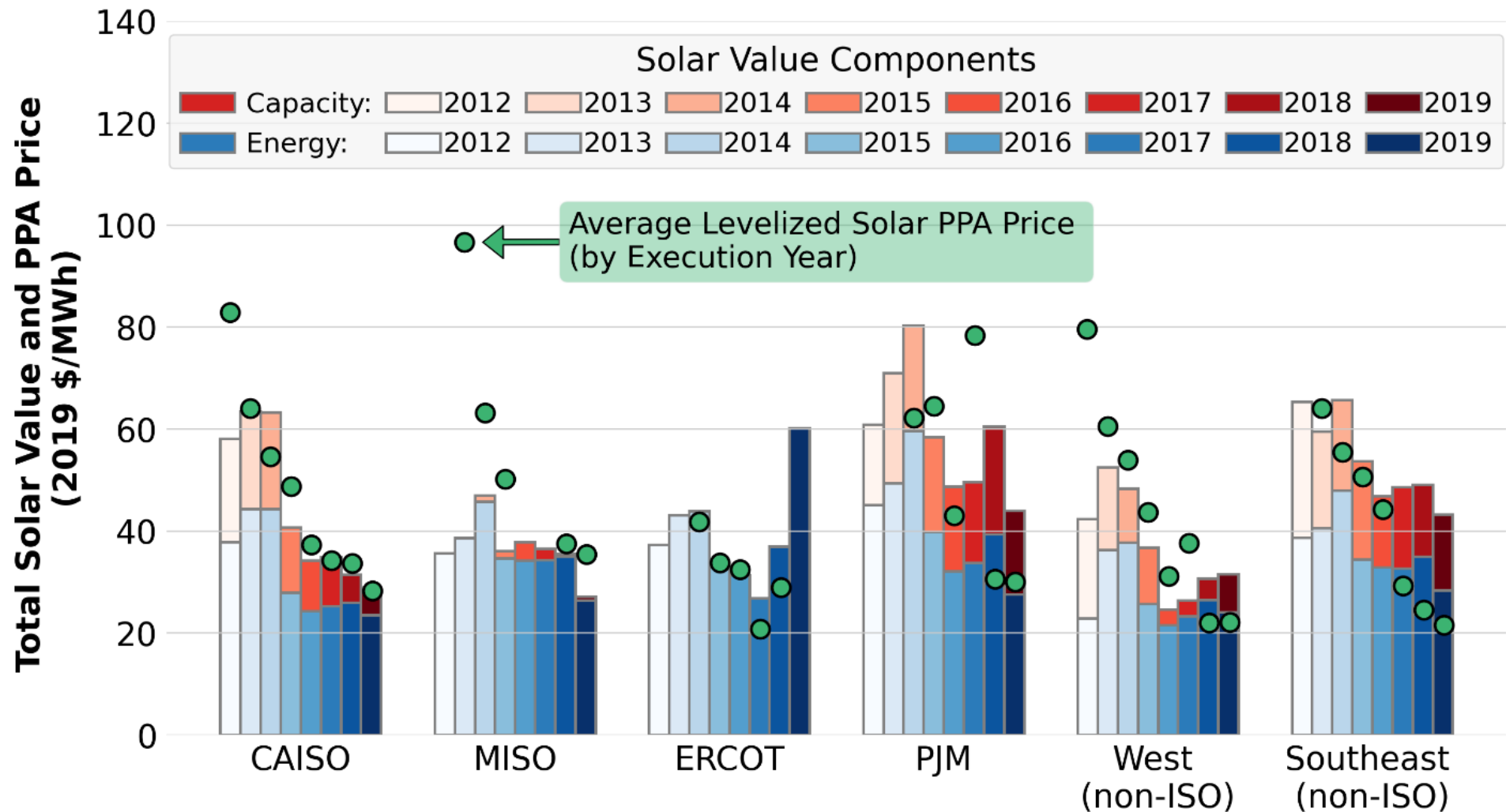


DA Market Participant



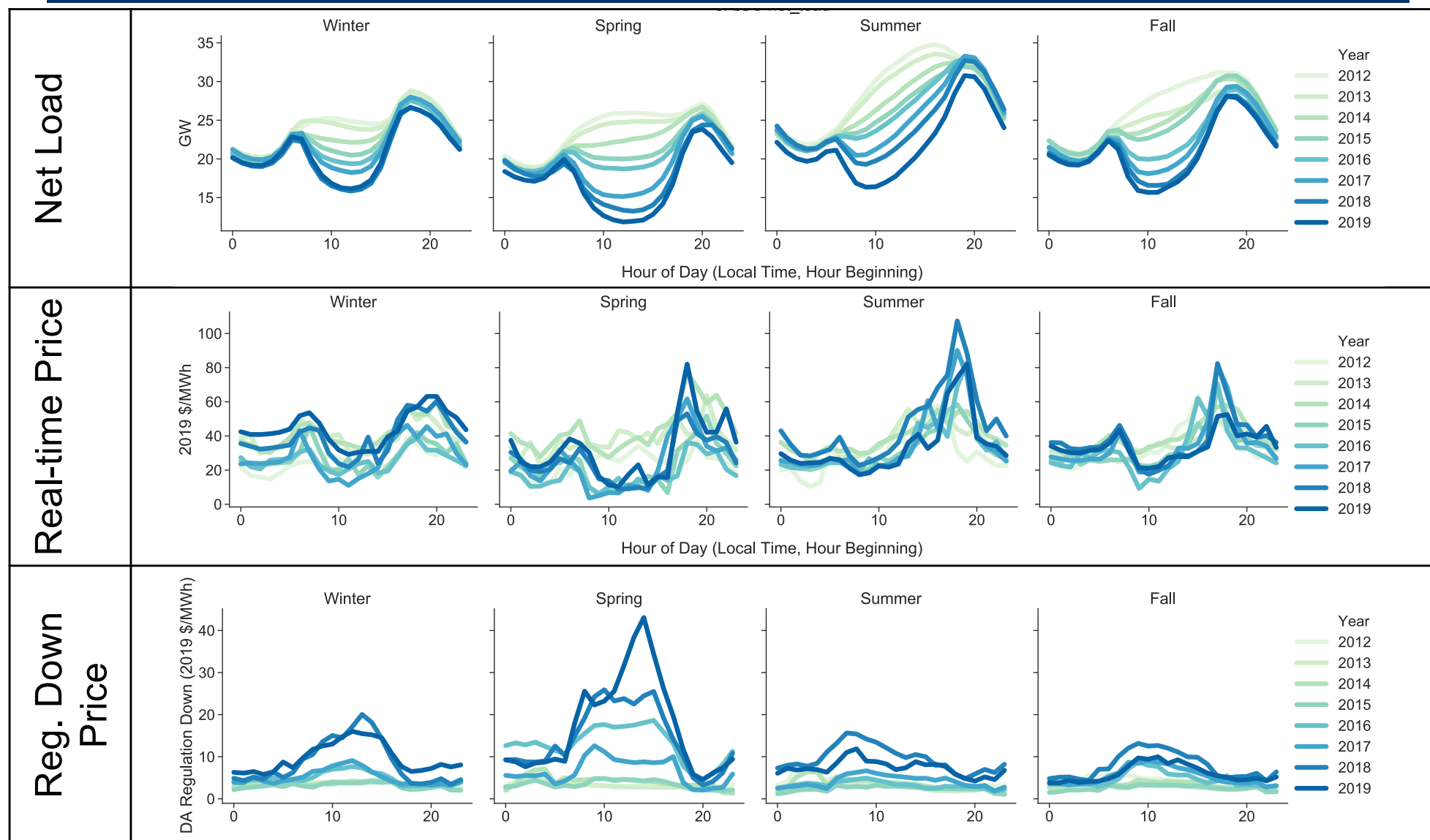
Note: Previous energy value results were based on real-time market value. Participation in the day-ahead market decreased value by \$0.50/MWh in 2019 when using the NAM-based forecasts.

Falling PPA prices have largely kept pace with declining solar value, more or less maintaining solar's competitiveness



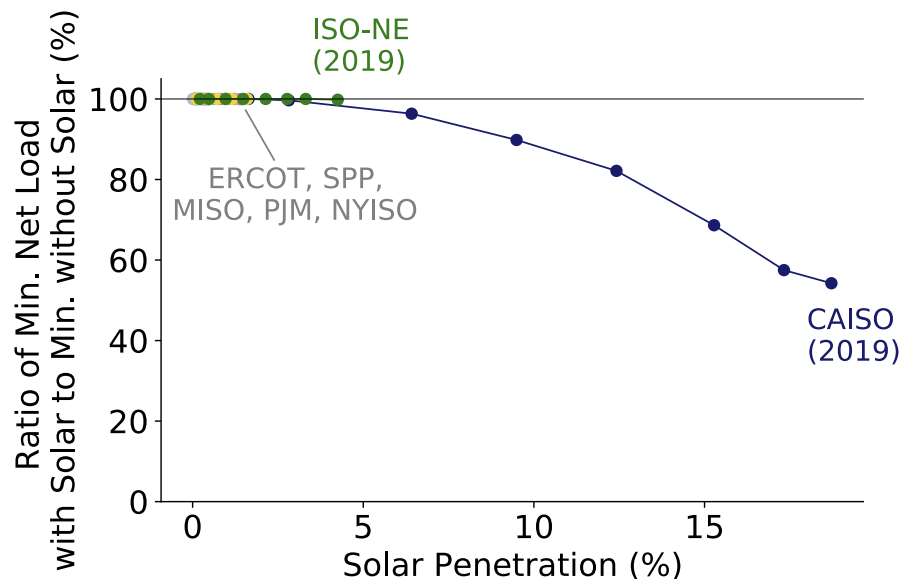
Impact of solar on the bulk power system

Obvious impacts of solar on CAISO net load and wholesale market prices

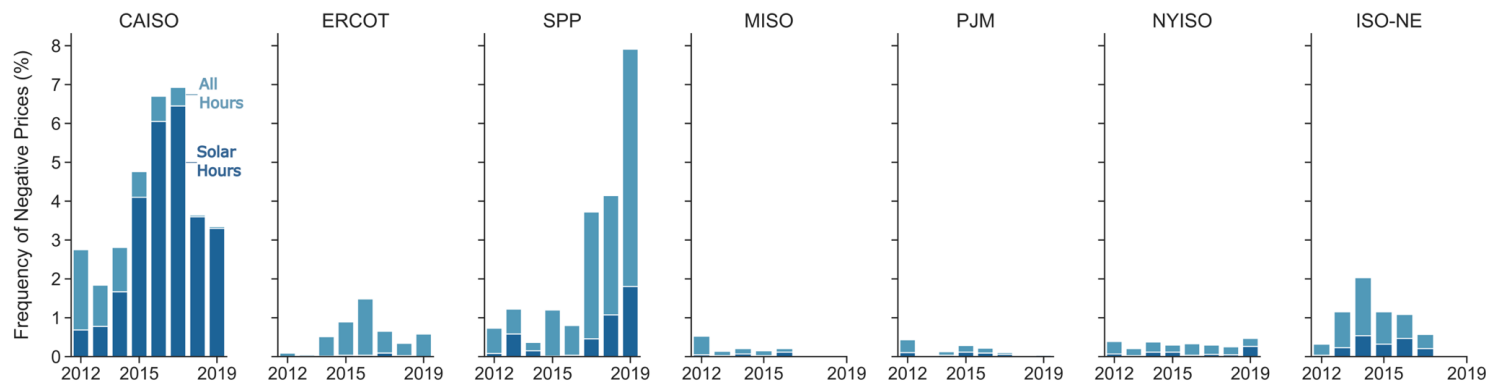


Lower minimum net load due to solar contributes to negative prices in CAISO

Lower minimum net load in CAISO

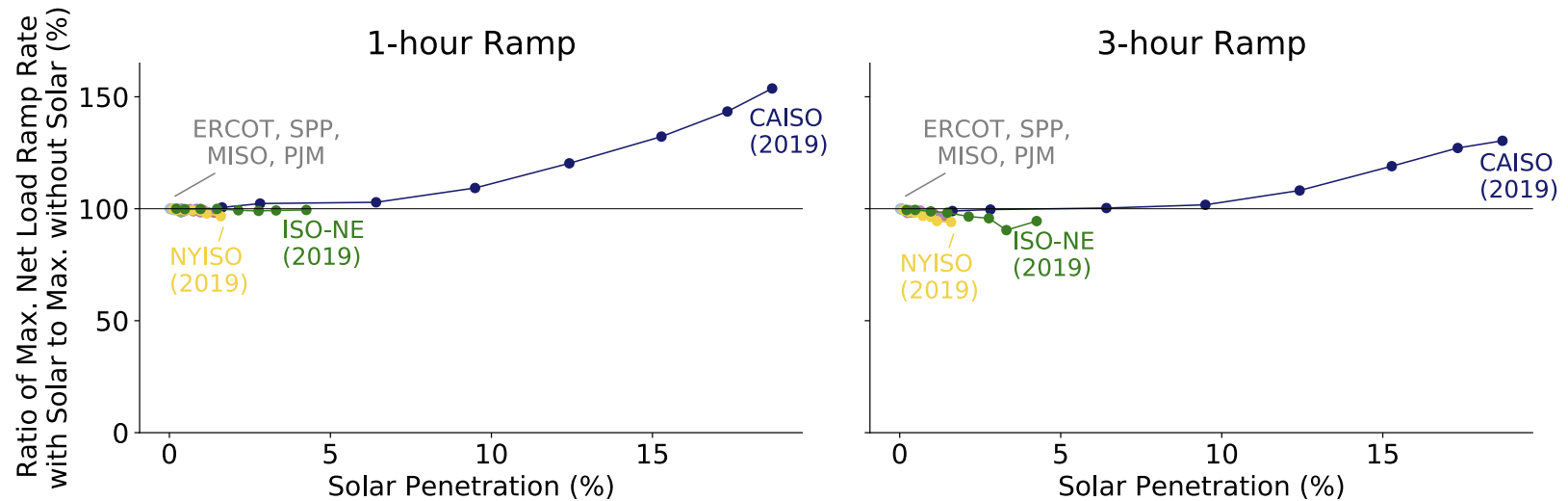


Negative prices occur during solar hours in CAISO

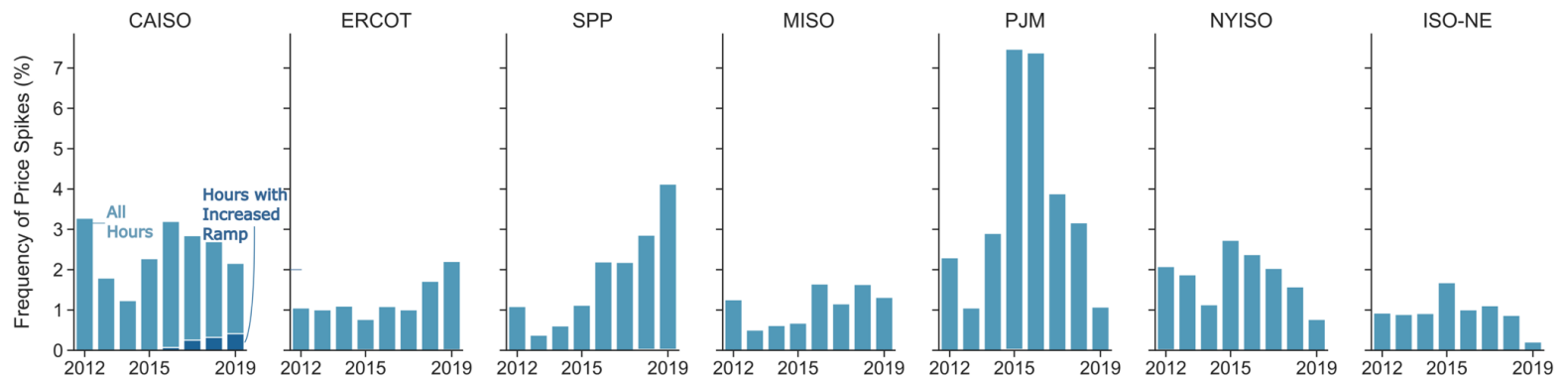


Higher net load ramps due to solar are beginning to contribute to price spikes in CAISO

Higher net load ramp rates in CAISO

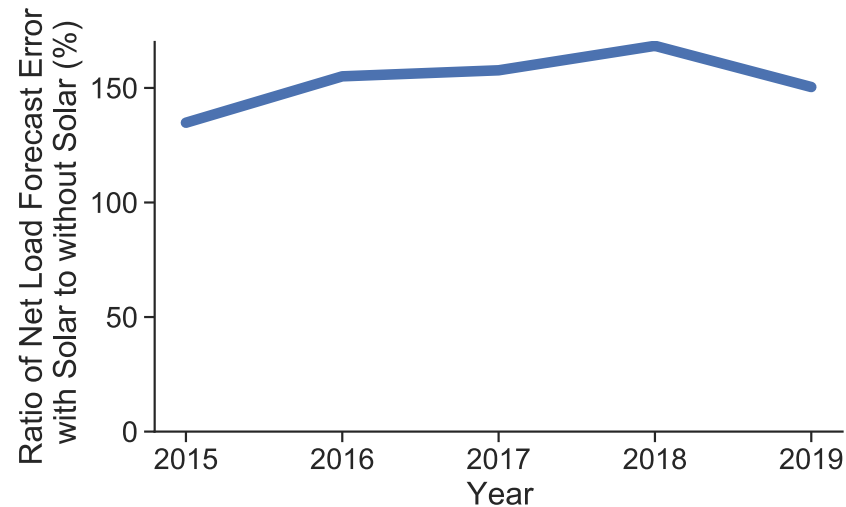


Price spikes beginning to occur at times of high solar ramps in CAISO

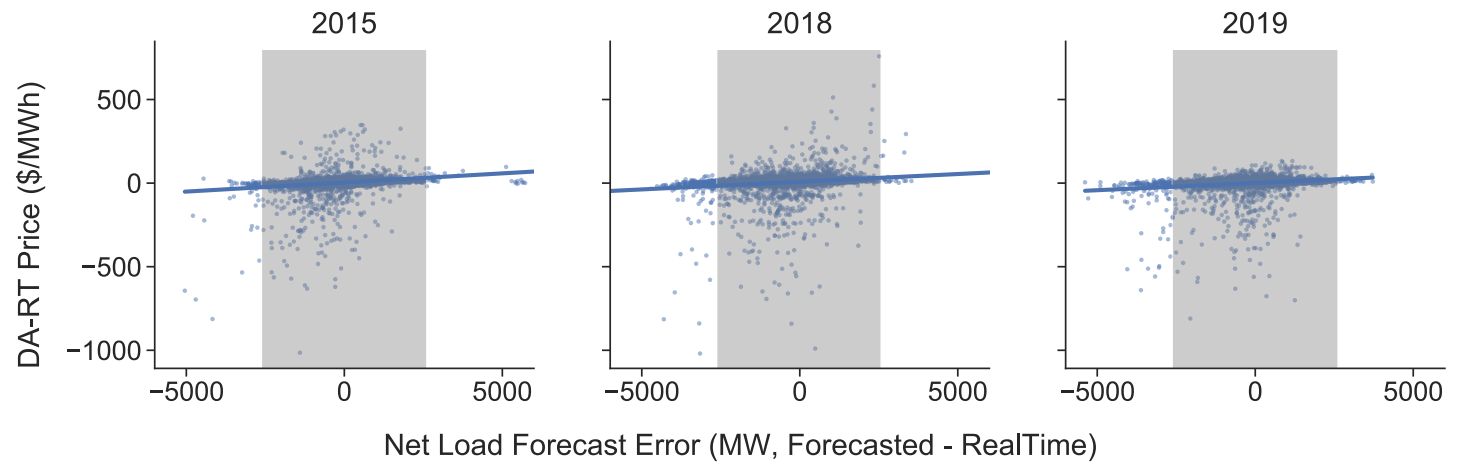


Solar forecast errors increase uncertainty between day-ahead market real-time markets in CAISO, though price impacts are limited

Higher day-ahead forecast errors due to solar in CAISO



Little evidence that abnormally high net load forecast errors consistently drive extreme differences in the DA and RT prices



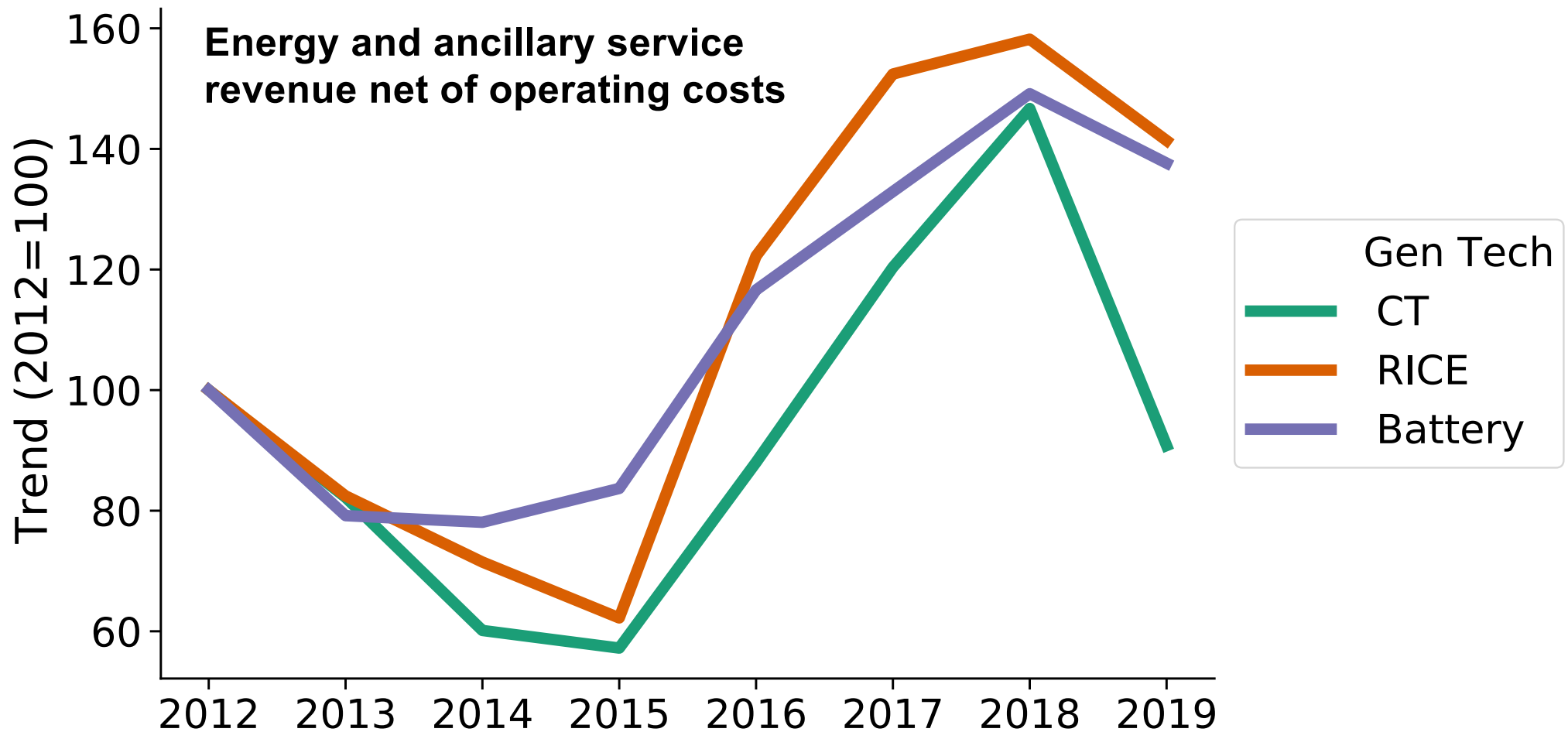
Note: The gray-shaded regions include 99% of all net load forecast errors without solar

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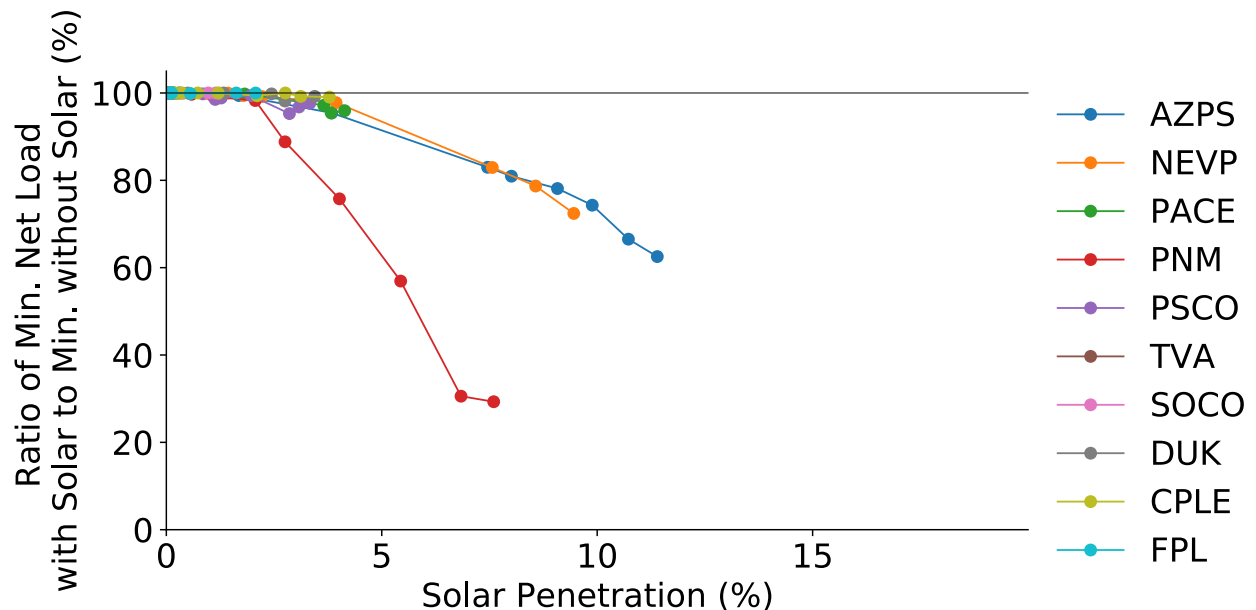
Incentives to invest in flexible resources in CAISO increased since 2012



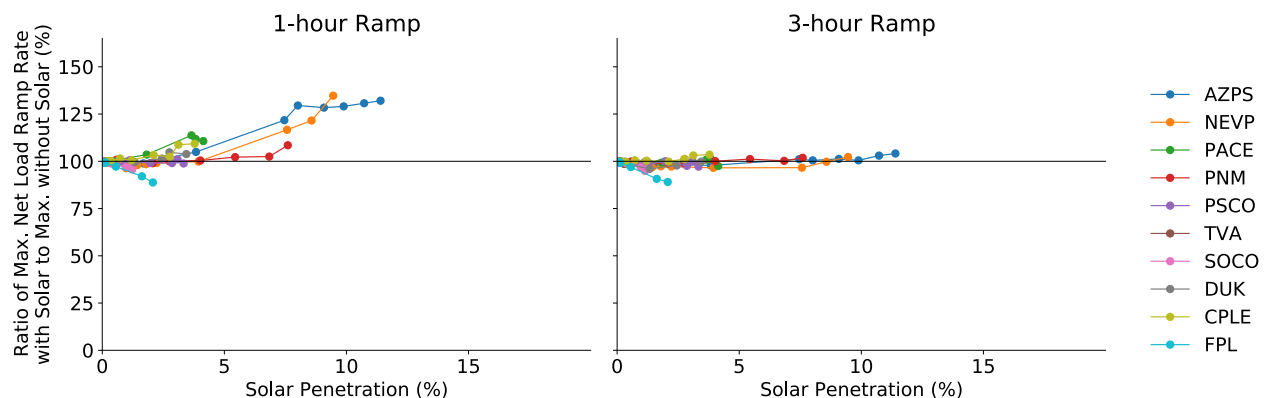
Solar is increasing the need for flexibility in some utilities outside of ISO/RTO regions

Lower minimum net load with solar in the Southwest

Solar growth shifted the minimum net load from nights to days in the spring and late fall



Higher net load ramp rates, especially in 1-hour net load ramps



Solar production on days of high risk of outages relative to average solar production in the same month

NERC System Risk Index (SRI): A high SRI indicates a day with severe challenges with generating and delivering power to U.S. loads

	Event Type	SRI	Date	CAISO	ERCOT	SPP	MISO	PJM	NYISO	ISO-NE
Summer	Thunderstorm Derecho	8.87	2012-06-29				0.9	1.1	1.1	1.0
	Severe Weather	4.40	2015-06-30	0.8						
	Coincidental Generator Outages	3.49	2016-06-20	1.1		0.7	1.1	1.2		
	Severe Weather	3.38	2015-07-18	0.5			1.0			
	Thunderstorms/Showers	3.30	2015-07-20	0.8	1.1	0.9	0.9	1.1	1.1	1.0
	Severe Weather	3.24	2015-06-23					1.0	0.9	0.8
	Severe Weather	3.20	2015-07-13					0.9		
	Summer Weather	3.10	2015-07-30	0.8	1.1	1.0	1.1	0.8	0.7	0.7
	Severe Weather	3.06	2016-08-11					1.1		
Other Seasons	Polar Vortex	11.14	2014-01-07		0.9			1.6		
	Polar Vortex	8.02	2014-01-06		0.8			0.6		
	Hurricane Sandy	7.17	2012-10-30						0.5	0.5
	Hurricane Sandy	7.04	2012-10-29						0.2	0.2
	Storm, Flooding, Straightline Winds	4.45	2015-11-17	1.1						
	Winter Storm Riley	4.22	2018-03-02						0.1	0.1
	Winter Storm Grayson	4.06	2018-01-02		0.4	1.0	1.0	1.4	1.1	1.0
	Winter Storm Avery	4.05	2018-11-15					0.1	0.2	0.4
	Winter Storm Juno	3.86	2015-01-08						1.3	1.4
	Excessive Rainfall, Thunder/Lightning Storm	3.79	2015-10-23		0.5	0.6				
	Coincidental Generator Outages	3.61	2017-05-01					0.8		
	Winter Storm	3.34	2019-02-24					0.4		
	Winter Storm Jayden	3.29	2019-01-30			1.3	1.3	1.6		
	Saddleridge Fire	3.25	2019-10-11	1.1						
	Winter Storm Indra	3.20	2019-01-21					1.7	1.2	1.1
	Winter Storms Quiana and Ryan	2.93	2019-02-25					1.8		

- Suggests solar, at least during daytime hours, mitigates stressful periods in the summer
- Contributions of solar in the non-summer months are more mixed depending on the event



Other impacts of solar on the bulk power system

- Inverter performance during disturbances
 - NERC has identified potential reliability issues associated with bulk power system-connected PV resources and their inverter settings
 - Noted loss of solar generating resources during disturbances to the bulk power system
 - Includes both tripping-related challenges and response to large voltage disturbances
- Maintenance of adequate frequency response with increasing levels of solar PV and other inverter-based resources
 - CAISO identified challenges with maintaining adequate frequency response as the share of inverter-based renewables increases
 - CAISO contracts with neighboring utilities to transfer a portion of its frequency response obligation, actions are not included in market prices
- Visibility and representation of DPV in system operations and planning
 - NERC identified gaps in representing the potential impacts of distributed energy resources on the bulk power system
 - Recommend modeling these resources explicitly in planning studies rather than netting them with load, improving representation of the resources in power system models and sharing data across the transmission and distribution interface



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